Robert L. Bates

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The Association of Geology Teachers
October, 1951

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NOTES AND NEWS

Eastern Section. An Eastern Section of the Association of Geology Teachers was organized on November 18, 1950, when a group of twenty-two interested persons brought together by the G.S.A. annual meeting in Washington, D.C., met for this purpose. Ralph Digman of Harpur College, Endicott, N. Y., was elected president pro tempore. The first regular annual meeting of the Eastern Section was held April 20-21, 1951, at Lafayette College, Easton, Pa. At this meeting Chilton E. Prouty of the University of Pittsburgh was elected president; A. Scott Warthin, Jr., of Vassar College, vice-president; Milton T. Heald of West Virginia University, secretary-treasurer; and Lawrence Whitcomb of Lehigh University, editor.

A joint meeting of representatives of the Eastern and Midwest Sections is to be held in connection with the G.S.A. meeting in Detroit, November 8-10, 1951. Plans for coordinating activities of the two sections will be discussed at that time.

Second Conference on the Teaching of Earth Science in the Secondary Schools. Under the chairmanship of C. Wroe Wolfe of Boston University a second conference on earth science education in the secondary schools was held at Harvard University, March 16-17, 1951. Speakers included Kirtley F. Mather of Harvard University; Herbert B. Nichols of the U. S. Geological Survey; Chester R. Longwell of Yale University; John H. Moss of Franklin and Marshall College; David M. Delo of the American Geological Institute; Waldo Holcombe of the Brooks School, North Andover, Mass.; Mary E. Mrose of Salem State Teachers College, Salem, Mass.; Ben H. Wilson of the Joliet Public Schools, Joliet, Ill.; and C. Wroe Wolfe of Boston University. The meeting was sponsored by the Earth Science Institute.

Reports on the activities of the Earth Science Institute have been carried in the monthly issues of

the Earth Science Digest. Unfortunately, the Digest was forced to suspend publication last spring. Miss Mrose's contribution to the second conference on earth science education is printed in this ussue of the Journal of Geological Education. Persons desiring further details on the conference should communicate with Professor Wolfe.

Indexing of the Journal of Geological Education. We are happy to report that articles appearing in the Journal of Geological Education will henceforth be indexed in the U. S. Geological Survey's "Bibliography of North American Geology."

We have approached the editors of "Education Index" and are advised that before we can secure coverage in this widely used medium our inclusion must be requested by "a good number" of the Index's library subscribers. Coverage in the "Education Index" will definitely help to extend the Journal's influence in the secondary school field. It is hoped therefore that our readers will request their librarians to take the necessary action.

Directory of Geology Departments. In July, 1949, the Association of Geology Teachers issued a mimeographed list of geology departments, and departments including geology, at four-year colleges and universities in the United States. This followed by four months the appearance of the A.A.P.G. "Directory of Geology Departments in the United States and Canada." We considered our list as something better than a scaled-down duplicate of the A.A.P.G. contribution inasmuch as we listed 241 different institutions in the United States which offered courses in geology, whereas the A.A.P.G. directory, which was based on their membership files, gave only 152. In June, 1950, we issued a supplement which added thirteen more institutions to our list.

The American Geological Institute has now undertaken the task of preparing an annual directory similar to the one issued two and a half years ago

by the A.A.P.G. Work is progressing on the current issue under the direction of Dr. Shepard W. Lowman of Rensselaer Polytechnic Institute. This new directory promises to be a real service to the profession. The Association of Geology Teachers has gladly passed on to Dr. Lowman all pertinent information which we had secured in the preparation of our own directory.

Geology: Gaining or Losing? At the annual spring meeting of the Midwest Section of the Association of Geology Teachers, it was reported that various established geology departments were scheduled to be discontinued in 1951-52. It seemed possible that precarious financial circumstances resulting from the loss of students to the armed services might be leading to a fairly widespread movement among smaller colleges to discontinue geology as a "non-essential" field of study. It was felt that, if this were so, there was real cause for alarm and the profession should be informed. Accordingly, in July of this year, a questionnaire was sent out to one geology teacher in each state asking for the names of any colleges contemplating discontinuance of geology in 1951-52 and also for the names of those expecting to initiate new departments.

Reports were received from thirty-seven of the forth-eight states. Not heard from were Kansas, Kentucky, Louisiana, Minnesota, Nebraska, Nevada, North Carolina, Oklahoma, Virginia, Ohio, and the District of Colunbia. In general, results were reassuring. Gains and losses appear to be approximately balanced. Some of the persons reporting were not altogether sure of their information, but three new departments were definitely recorded, as against four departments discontinued. Gains were in Massachusetts, Mississippi, and New York; losses in Illinois, Indiana, Pennsylvania, and Vermont.

While the situation is not therefore alarming, there is certainly no cause for complacency. Of 291 four-year colleges on the "approved" list (1947) of

the Association of American Universities only a little over half, according to latest information available to A.G.T., have geology departments or offer any regular instruction in geology. The ratio in the many other schools, which for one reason or another do not happen to be included in the A.A.U. list, is presumably no better. This, we feel, is not a wholesome situation. Geological instruction should be far more widespread in the colleges. If the science is merely holding its own, there is cause for concern.

Note on Fisher's Paper in Preceding Issue. Dr. D. J. Fisher asks us to call attention to the fact that the numbers following author's name and date in his "Index to Determinative Tables," pages 13-14 of our preceding issue, are page numbers. Dr. Fisher's paper is entitled "Mineralogy for Embryonic Professional Geologists."

POPULAR GEOLOGY

Arthur Montgomery
Lafayette College

Fifty or sixty years ago geology enjoyed a greater popularity than it does today. Lectures by famous geologists attracted wide public attention, and it was not a bit unusual for private homes to have in them cabinets filled with fossils and minerals. Courses in physical geography were given in many schools where hardly more than a bare trace of geology is taught at present. It seems that in earlier days an interest in earth science was regarded as one of the marks of culture.

The reasons for this drop in public favor are due in large part to the changed character of geology. Where it used to be a broadly descriptive science, geology has now become increasingly analytical and specialized. This is of course a reflection of the rapid technical advance of all science. That such progress in geology has been greatly to be desired cannot be denied, but it is evident also that with the technical advance something vital has been lost. What has been lost is that which used to appeal most to the layman and which helped make earth science a popular subject. It is the <u>story</u> geology has to tell of the past history of the earth, a story of ageless mystery and fascination.

The explanations for many geological phenomena given by the old-time teachers of earth science seem to us now inadequate, but at least they made a fairly simple and straightforward picture which the layman could comprehend in its entirety. Now the tiny and detailed brush strokes stand out so sharp and clear in the foreground that the whole of the background picture, its broad meaning and its purpose, fade out and are almost lost to view. The older account, unencumbered by detail, had the power to explain the

earth in a vital and personal way to the listener and make him start wondering on his own about its surface features, the hidden depths beneath its crust, its changes, and its past. With the accumulation of great numbers of new facts, it is as if the flavor of the subject, so far as human taste is concerned, had been lost.

It is highly significant that in the past few years something of the old popular approach has started coming back into the teaching of geology. Early signs of it were to be observed at the conferences on "Training in Geology," held under G.S.A. auspices from 1945 to 1948. Although a majority of the participants were preoccupied with the turning out of more rigorously trained geologists, a few spoke out strongly in favor of less rigor and greater popularity for the subject. The program of the American Geological Institute is a noteworthy sign of the new viewpoint, for its concern is mainly with public relations, the impact of the science on the world outside, and improvement of the status of geology in general education. The Institute's survey of geology teaching in American schools and colleges will prove an enormous contribution to self-knowledge in the field of geologic education. Less publicized, but perhaps still more influential in a quiet way, are the expanding activities of the Association of Geology Teachers.

Many geologists think of educational progress in earth science not in terms of how geology educates the layman, but in terms of how geologists educate their own kind. The outward educational influence is considered to be a by-product of this last. The demand for more rigorous training of potential teachers of earth science derives from this viewpoint. But there are two types of geology teaching to be considered and it is essential at all times to keep them distinct. One is the teaching of vast numbers of elementary students who are fundamentally laymen and who will never take another course in

earth science. The other is the more specialized teaching, on a high level, of a few students committed to serious study in the field. It is true that elementary courses will fail to educate either in a popular or scientific way if they are not based on thoroughly sound and authentic geology, but it is also true that there cannot be any cultural value to such courses unless constant effort is made to relate earth science to the life of the average individual and to the environment which he sees about him.

Geology has perhaps the highest cultural potential of any physical science, yet is there a single primarily cultural course in earth science being given anywhere today? What about geology as the explanation of man's environment? What about the lessons to be derived from the history of the science--from the lives, thoughts, and discoveries of the men who have most advanced it on its way? What about instruction in the facts behind American scenery and natural resources--not aimed at the textbook-cramming student but at the cross-country traveler and the average business man? What about a course in the methods of geology, exemplified by actual case histories, past and present, and with various specialists as guest lecturers? C. K. Leith's "World Minerals and World Politics" is one example of a text aimed in the right direction, but how many courses with this sort of orientation are being given, and how many of those that are given direct attention to the exciting human stories behind some of the great discoveries of mineral resources?

The Institute is not the only influence working in the direction of a more popular geology. A number of projects are under way where individual teachers of earth science or entire college departments are engaged in efforts to make geology more practical, understandable, and interesting for the layman. Talks on radio and television are being given, as well as popular lectures before various lay organ-

izations. An outstanding example is supplied by the staff of the geology department of Franklin and Marshall College which has been presenting a series of popular talks before high school students and service clubs. This department has also made a color film on "The Geologist at Work" which is to be widely shown in Pennsylvania, especially to high school audiences. This undertaking is almost unique in its recognition of the fact that the work and usefulness of present-day geologists are practically unknown to the general public.

It is of course easy (one might almost say fashionable) to criticize scientists for too narrowly scientific a viewpoint. The truth of the matter is that many geologists are fully aware of the educational problems confronting their science and are quietly doing something about them. Some of this activity has been in operation for a long time. An example is to be found in the series of geologic quadrangle reports published over fifteen years ago by the New Hampshire Planning and Development Commission under the leadership of Marland P. Billings of Harvard University. These reports made available to the interested public, at very small cost, highly readable as well as authentic accounts of the progress of geologic mapping in that state. They showed how geologic maps are to be interpreted and how they can add to the understanding of one's local environment.

Most far-reaching of all efforts to make earth science a more popular subject are the individual cases where geology teachers add to their presentation of factual data and textbook principles (which have to come first) some element of human interest which can transform a listless student into a wholly receptive one and remake a notably dull subject (as it emerges from the testbook) into one of vitality and practical meaning. Most of these efforts go on quietly and unsung so far as public recognition is concerned, but this kind of teaching never fails to make an impression on the outside world. Its

influence spreads, like ripples from a thrown stone on the surface of a pond.

More than any other science, except perhaps astronomy, geology has inherent in it the capacity for capturing the quick interest of those who live upon the surface of the earth. It is not as mysterious as the realm of astronomy, but it is far more real and far more accessible to observation and understanding. It is doubtful whether any teacher of earth science, however strictly scientific he may be, has escaped the thrill of sudden immersion, somewhere in his own early training, into the sounds and scenes of the very ancient past, with its glimpses of landscapes other than any now to be seen, and the accompanying vivid awareness of being part of an evolutionary process transcending the vicissitudes of time.

It is above all else true that the growing efforts to popularize geology and make it of use and pleasure to the average man are not alone dictated by the science's preoccupation with self-survival. They are dictated also, though the geologists concerned may be the last to admit it, by a larger sense of social responsibility. It is this larger sense of responsibility which causes the scientist to look up for a moment from his dedicated task and pass on his message to the world.

A METHOD OF TEACHING HISTORICAL GEOLOGY

Robert H. Mitchell
Muskingum College

Historical geology is frequently taught as a factual course. Too often the student is expected to memorize the facts of geologic history without an understanding of the methods by which these facts were established. When such is the case the course has little practical value, whether the student is preparing for a geological career, or taking the course simply for its cultural value. But historical geology can be of great value to both these groups.

In undergraduate work it is most important that a student learn to think clearly and accurately and that he be able to draw valid conclusions for himself. Historical geology can be a valuable tool in such training.

The student who plans a career in geology and who will go on to graduate school will take one, or perhaps two, other courses in geologic history in which he will have ample opportunity to learn the "facts" of earth history. If in his undergraduate course he has learned the methods by which these facts were established, the advanced courses should then be of more value to him. Certainly a career geologist must be able to interpret data. Factual courses in historical geology too frequently neglect this training. It has been said that anyone can collect data, but success comes to him who can interpret it.

It should be one of the objectives of a liberal arts (or so called "cultural") course to train the student to think clearly and accurately. If this objective dominates, then the subject matter of a course serves only as the basic material about which thinking is to take place. Historical geology is admirably suited to this approach. It offers the

instructor opportunity to present data and from these data lead the student to clear and logical conclusions. Such conclusions, presented just as "facts" (to be learned only to pass an examination) are soon forgotten, but when a student masters the principles and techniques of deriving the facts of earth history, he has a new basis for understanding and enjoying his environment.

At Muskingum College, historical geology is taught in the second semester of a one-year course in general geology. For a number of years we have been teaching the course with the above-described philosophy in mind. The student is told that he must think for himself and draw his own conclusions from the data presented. He is told that he need not agree with the interpretation of the text, the instructor, or his fellow students, but that he is expected to have a valid reason for his agreement or lack of agreement.

Certain facts concerning the earth must, however, be known if the student is to draw valid conclusions. To satisfy this need we have prepared a special mimeographed text[1] in which certain facts of rock composition, distribution, etc., are presented. From these basic facts, the history of the earth is derived step by step.

At the beginning of the course we depart from the conventional method of first considering theories of the formation of the earth. Instead we start with the Pre-Cambrian. This is done in order to let the student discover that the Pre-Cambrian is the oldest manuscript from which we can obtain direct evidence on the events of earth history.

The Pre-Cambrian rocks--their structure, distribution, reported evidences of life, etc.--are described,

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[1] "Earth's Diary" by Robert H. Mitchell, 1941. (Now out of print.)

and from these data the history of Pre-Cambrian time is interpreted step by step so the student may follow the reasoning used.

As the events of Pre-Cambrian time are reconstructed, it becomes evident that the earth was in existence before Pre-Cambrian time and that certain events and processes were in progress when the oldest rocks we can find were being formed. Since we have no direct evidence of what happened before the earliest known Pre-Cambrian we must then theorize on the beginnings of earth history. It is pointed out that the events which led up to the Pre-Cambrian are closely related to the origin of the earth. Therefore the next step is to consider the theories that attempt to explain the earth's origin.

The more popular theories of the origin of the earth are discussed and their strong and weak points noted. It soon becomes obvious to the student that these theories cannot all be the correct explanation of the origin of the earth. Neither can we devise experiments to test the validity of any of them. We can, however, draw certain inferences as to conditions in Pre-Cambrian time which would logically be expected to follow from a given theory of origin. By testing these inferences against what we actually know about Pre-Cambrian rocks, we are able to select the theory which best fits the facts.

Our next step is to discuss in chronological order the eras and periods of later geologic time. The rocks of each period are described. Then the historical events of the period are reconstructed in the same manner as for the Pre-Cambrian.

We depart in one respect from a strict period-by-period presentation. Since the closing events of any period are reconstructed in part from the condition of contact between the rocks of that period and those of the following period we delay the discussion of closing events until we have presented the necessary data

regarding rocks of the succeeding period. Thus, the closing events of the Cambrian, for example, would be discussed and reconstructed only after we had described the rocks of the basal Ordovician.

The field work of the course is designed to further develop the student's understanding of the procedure by which the facts of earth history are arrived at. The writer has described elsewhere his field trip techniques with beginning students.[2] Three short conducted trips are taken, in which the student is given instruction primarily in taking and recording geologic sections. Later each student is assigned a road cut or ravine where he determines a section on his own. He brings his report and specimens he has collected to class on a designated day. The sections determined by various students are combined into a composite. From this and the specimens the geologic history of the immediate area is reconstructed in class.

Many of our readers may object to this kind of an approach to earth history on the ground that it is so time-consuming that the entire history of the earth could not be covered in a single semester. While it is true that the work progresses slowly at first, speed may be increased as the student becomes familiar with the procedure and gains proficiency in geologic thinking. Since this is a beginning course, and since we believe that it is more important that the student learn to think than that he master the facts of geologic history, we are not especially concerned if we do not cover the entire field. Any lack of detailed information which the student may suffer as a consequence is more than compensated by his increased ability to think for himself and not accept blindly the conclusions of others.

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[2] "Vitalizing Historical Geology Through Field Trips," by R. H. Mitchell, Science, Nov. 10, 1939, p. 441.

A REVIEW CHART FOR HISTORICAL GEOLOGY

Lawrence Whitcomb
Lehigh University

Outlines and charts have long been recognized as valuable aids when one reviews a subject. As a result there are certain outlines and charts that have been published and which are found on sale in many campus bookstores. While some of these aids for courses in historical geology are very good, I do not recommend their use. I feel that a student will get a great deal more benefit out of the time spent if he uses it to construct a review chart for himself.

As the main purpose of a chart is the organization of material, it is important that not too much time be spent on the mechanics of its construction. One crudely made, on a large piece of paper taken from a laundry bundle, is often of more value than one which has been nicely drafted with T-square and triangle. Space rather than beauty is the desirable thing.

The charts that I recommend have thirteen horizontal rows, one for the Pre-Cambrian and one for each of the subsequent geologic periods. These horizontal rows are in turn divided into fifteen or more vertical columns to which various headings are assigned. The spaces on this grid should be large enough to allow a considerable amount of data to be entered.

The first (left hand) column is filled in with the geologic time scale. The second contains data regarding the origin of the period--who named it, when, from what type section, and the source of the name. The third column can well be used to list the epochs of the period. From here on the subject for each column can well be left to the individual, but

certain subjects are suggested. Some of the obvious ones would be: United States distribution, foreign distribution, important formations, climate, names of people to be associated with the period, igneous activity, tectonic disturbances, economic products, important faunal or floral data, apparent intercontinental connections, and miscellaneous.

There are at least three ways in which the construction of a chart of this type helps the student. The first and most obvious is the fact that the mechanical work helps to fix data in his mind. The second is that it helps him to discover gaps in his lecture notes or knowledge; if a square is blank it immediately becomes very noticeable and he can check to see whether something has been missed or whether there is nothing to be inserted in that place. The third is that the chart allows him to consider a topic from two entirely different aspects. A horizontal row contains all of the data dealing with a particular period, while a vertical column gives the complete history of a particular topic in chronologic order. I believe that this last point is of special significance, for the normal procedure is to teach historical geology on a time basis, rather than a subject basis. Practically all textbooks are written period by period and most classes are taught in the same manner. As a result of this procedure students will have facts scattered throughout their notes that should be tied together. The chart does tie them together and helps to explain their interrelationships.

Probably the best recommendation for any chart is student reaction. Year after year men come around to me and say that their chart was the thing that helped them most in the course. It has now reached the point where the word is being passed down from one class to another that time spent in making one of these charts is justified by the results obtained.

THE SIZES OF ATOMS AND THE STUDY OF ELEMENTARY MINERALOGY

Donald M. Henderson
University of Illinois

Examination of the available mineralogic texts, and conversation with teachers of mineralogy, lead one to the conclusion that most courses in elementary mineralogy do not provide an adequate introduction to the science of mineralogy at the college level. The most fundamental weaknesses are that the approach is invariably dogmatic and that so much effort is directed towards the accumulation of large amounts of miscellaneous and empirical information. Generally, almost nothing is learned in a logical manner about the fundamental principles that control the make-up and properties of minerals, or about the significance of minerals and their properties as clues to the history of the crust of the earth.

The purpose of this paper is to direct attention to the necessity for a more fundamental approach to the study of elementary mineralogy, involving a simplified presentation of the basic principles of crystal chemistry. Most of these principles are simple enough to be understood and applied by the average student. A much clearer understanding of the complex relations of minerals can be gained from them. The numerous empirical data that accompany a course in mineralogy can be resolved by means of them into some semblance of order and significance. Moreover, the development and application of these principles for and by the student are a slight introduction to the scientific mode of thought, which is otherwise almost universally ignored in the study of elementary mineralogy.

Crystal chemistry deals with the arrangement of atoms and its effects upon the properties of crystalline substances. Inasmuch as almost all minerals are crystalline, it should be obvious that a rudimentary

understanding of crystal chemistry is fundamental to the study of even elementary mineralogy. No special background beyond an introductory course in inorganic chemistry is necessary for a simple understanding of the subject, although a review of the periodic arrangement of the elements is extremely helpful (Sisler, Van der Werf, and Davidson, 1949, ch. 9 and 10; Evans, 1948, pp. 11-19.[1])

Inasmuch as the basic principles of crystal chemistry are available in several texts (Stillwell, 1938; Evans, 1948; Wells, 1950) I shall not attempt to develop them completely but shall merely emphasize those that are most significant for the study of minerals. The evidence for most of the following statements can be found in the texts referred to.

In general, atoms may be thought of as spherical domains, which for practical purposes have definite sizes.[2] (Incidentally, the term "atom" will be used loosely to refer to the smallest units of elements whether they are atoms in the literal sense or whether they are ions.) The exact size of the domain of a given atom depends upon many factors, the most important of which are the element concerned and its valence state--that is, the nuclear and electonic structure of the atom itself. Although environmental factors such as temperature, pressure, nature of neighboring atoms, and the number of neighboring atoms also affect the size of a given atom, these factors can be ignored for present purposes. Figure 1 shows the approximate sizes of the most important atoms composing minerals. Note that in general the anions are larger than the cations.

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[1]Full titles of references are given at the end of this paper.

[2]For the significance of "atomic size" see Stillwell, 1938, footnote pp. 10-11, and ch. 2.

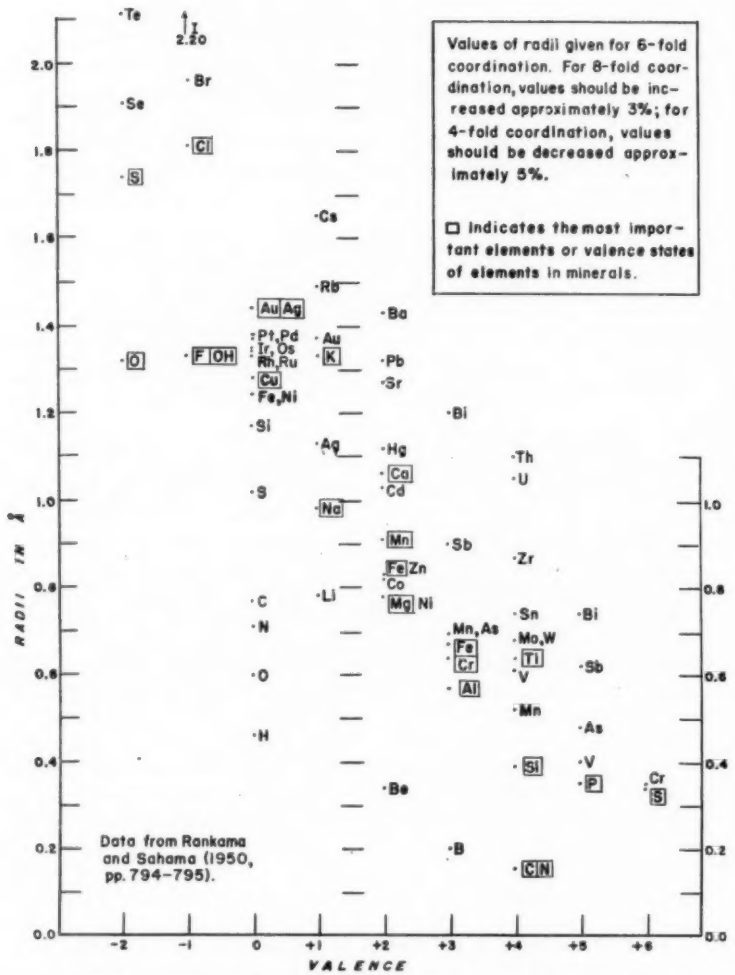


Figure 1— Approximate ionic and atomic radii of the important elements in minerals. (Modified after J.L. Rosenfeld)

This concept that atoms of different kinds and valence states have definite sizes is so fundamental to the study of the crystal chemistry of minerals that it has been singled out for attention in the title of this paper. Care must be taken, however, not to think of atoms as solid or rigid spheres such as golf or tennis balls, but rather as spheres of "influence" or spheres of "negative electricity" which have definite sizes but which are almost wholly empty space.

It so happens that most of the atoms composing minerals have electronic structures such that the atoms may be considered as ions--that is, electrically charged spheres of influence. As a result of the ionic nature of the units, the force that bonds such atoms to one another is relatively simple. It may be considered as an electrostatic attraction between negatively and positively charged spheres. The simple nature of this bonding force makes possible an easy understanding of the salient points of the crystal chemistry of most minerals. The electronic and nuclear make-up of the atoms composing many other types of crystals, like those of most organic solids, is such that the bonding forces are more complicated, and the crystal chemistry of these substances is correspondingly more difficult to explain. Covalent, metallic, and Van der Waal's bonding forces are recognized in addition to ionic bonding forces. Furthermore, these different types of forces grade into one another.

The sulfides and native elements are the most important groups of minerals which, for elementary purposes, may not be considered to be predominantly ionic. The sulfides and non-metallic elements are held together chiefly by covalent bonds, whereas the metallic elements are held together chiefly by metallic bonds. Nonetheless, the concept of atomic size is useful in explaining many properties of even these minerals. Atomic sizes are used for most such minerals rather than the ionic sizes used for most other minerals. (See zero-valence column of Figure 1.)

Where electrostatic attraction occurs between cations (positive) and anions (negative), it has been found by study of the energy relations in crystals that the ions are arranged in the most stable manner when the spherical domains of the anions just "touch" those of neighboring cations and vice versa. Furthermore, as many anions as possible are attracted so as to surround and just "touch" each cation and vice versa.

If the foregoing statements hold, it is not difficult to infer that the arrangements of atoms in minerals are controlled chiefly by the geometric limitations upon the ways that spheres of different sizes can be packed together repetitively.

As a simple illustration we may consider a compound consisting only of cations C and anions A in equal numbers. The familiar substance NaCl is such a compound. The atomic structure of the compound depends mainly upon how many anions A surround each cation C and vice versa. A little three-dimensional visualization or manipulation of actual spheres will quickly show that the number of A spheres that can fit around a C sphere depends upon the sizes of the spheres. A little more visualization or experimentation will lead to the conclusion that certain definite ratios exist between the sizes of the spheres which delimit the different kinds of possible arrangements. In the parlance of crystal chemistry, the ratio of the radius of the C spheres to that of the A spheres is known as the radius ratio, and the number of A spheres that can fit around and just "touch" each C sphere is known as the coordination number.

Table 1 lists the most important coordination numbers and arrangements or configurations of spheres and their limiting radius ratios. The significance of Table 1 may be illustrated by reference to the case of three-fold coordination. Three A spheres can fit around and touch each C sphere if the ratio of the radius of the A spheres to that of the C spheres is

0.155 or greater. However, if the radius ratio is 0.225 or greater, four A spheres can be packed around each C sphere. Figure 2 may help to show why this is so. Figure 2,a, illustrates the limiting case for three-fold coordination, where the radius ratio is 0.155. Figure 2,c, shows that if the radius ratio is less than 0.155, the A spheres cannot all touch the central C sphere. As already mentioned, such a configuration is not a stable one because the energy requirements are not satisfied. If the radius ratio is greater than 0.155 all the surrounding A spheres can touch each C as is shown by Figure 2,d. Finally, if the radius ratio is large enough, 0.225 or greater, there is sufficient room for a fourth A sphere to fit in behind and touch each C sphere as in Figure 2,e.

TABLE 1

No. of A-spheres around each C	Limiting radius ratios	Diagrammatic geometric configurations
2	0.000	
3	0.155	
4	0.225	
6	0.414	
8	0.732	
12	1.000	

It should be clear by now that minerals held together by ionic bonds are not composed of molecules in the literal sense of the term. This is because the configuration of one kind of atom around another is

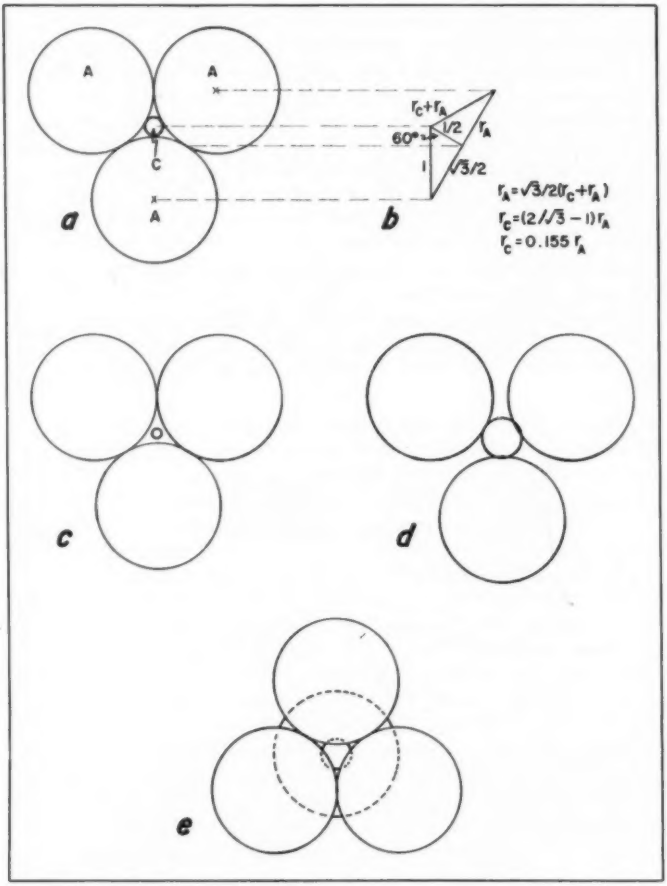


Figure 2— Control of the packing of spheres by their relative sizes. *a*) limiting case for 3-fold coordination, *b*) calculation of the limiting radius ratio for 2σ, *c*) radius ratio less than 0.155, *d*) radius ratio greater than 0.155, *e*) 4-fold coordination — possible when radius ratio is 0.225 or greater.

not controlled by valence but by the relative sizes of the atoms. The role of valence may be elucidated most easily by reference to some simple mineral compounds.

Consider first a CA type of compound such as CsCl. The radius ratio (Cs/Cl = .91) demands that each Cs atom be surrounded by eight Cl atoms and vice versa (See Figure 1 and Table 1). Figure 3,a, depicts the positions of the centers of the Cs and Cl atoms and shows that every Cs atom is equally associated with eight Cl atoms and that every Cl atom is likewise equally associated with eight Cs atoms. The only effect of valence upon the structure is to require that the number of cations and anions be equal.

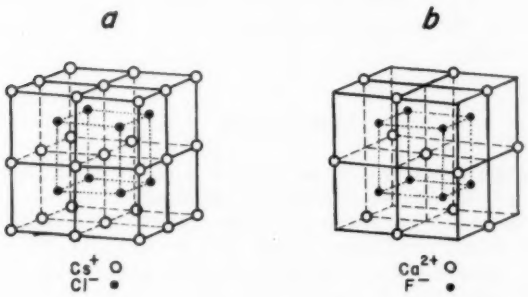


Figure 3— Effect of valence upon crystal structure. *a*) CsCl — a CA-type compound, radius ratio 0.91, in which eight Cl^- surround each Cs^+ and eight Cs^+ surround each Cl^-. *b*) CaF_2 — a CA_2-type compound, radius ratio 0.80, in which the structure is identical to that of CsCl except that Ca^{2+} occupies only the alternate Cs^+-type positions.

Next, consider the atomic structure of a CA_2 compound, such as CaF_2, for which the radius ratio (.80) is similar to that of CsCl. As shown by Figure 3,b, the structure is similar to that of CsCl except that Ca^{2+} atoms occur only in every other one of the posi-

tions equivalent to those occupied by Cs^{+} atoms in CsCl. This is simply because there are only half as many Ca^{2+} atoms as F^{-} atoms. In other words, the chief effect of valence upon crystal structure is control of the relative number of the different kinds of atoms present in a given arrangement. Not all of the places afforded by a particular arrangement need be filled.

Most minerals, of course, contain more kinds of atoms than do the simple C_mA_n-type compounds which have been used here for illustration. Accordingly, it is commonly difficult to apply the radius ratio principle simply and directly to the determination or prediction of atomic structures of minerals. Nonetheless, the same general principle still holds: the relative sizes of the atoms largely control the construction of the mineral. Some important applications of this principle will be demonstrated in the following sections.

Isomorphism

Although isomorphism occurs to a significant degree in most of the known species of minerals and to a high degree in many, it seems that few textbook writers or teachers attach to isomorphism the importance it deserves. As a result, few students of mineralogy have a true conception of the nature and properties of real minerals.

The concept of isomorphism may be developed best, perhaps, by reference to specific examples. Examination of a collection of analyses of almost any of the common minerals generally shows wide latitude in the amounts of one or more of the constituents. For example, Table 2 lists several slightly simplified analyses selected to show variations in composition for olivine and magnetite. In order that we may make use of the data in Table 2, however, it is necessary to present them in recalculated form. Table 3 gives the relative numbers of atoms present rather than their total relative weights.

TABLE 2

Representative analyses of olivine.

SiO_2	42.1	38.4	33.3	30.0
MgO	54.6	38.6	16.8	2.0
FeO	3.3	23.0	49.9	68.1
	100.0	100.0	100.0	100.1

Representative analyses of magnetite.

Al_2O_3	0.76	6.57	0.00	10.37
Fe_2O_3	68.48	65.45	68.20	61.63
Mn_2O_3	0.00	0.10	3.32	0.00
MgO	.40	6.74	4.98	9.47
FeO	30.41	18.72	21.90	16.24
MnO	tr.	3.40	1.50	2.10
	100.05	99.98	99.90	99.81

TABLE 3

Relative numbers of atoms in olivine.

Si	1.00	1.00	1.00	1.00
Mg_{2+}	1.93	1.50	.75	.10
Fe^{2+}	.07	.50	1.25	1.90
O	4.00	4.00	4.00	4.00

Relative numbers of atoms in magnetite.

Al	.03	.27	--	.42
Fe^{3+}	1.97	1.70	1.91	1.58
Mn^{3+}	--	.03	.09	--
Mg_{2+}	.02	.35	.27	.46
Fe^{2+}	.98	.55	.68	.48
Mn^{2+}	--	.10	.05	.06
O	4.00	4.00	4.00	4.00

Inspection of Table 3 shows that although the relative numbers of the metallic cations in olivine can range through all proportions of Fe^{2+} to Mg^{2+}, the sum of the relative numbers of these cations is constant. A similar though slightly more complicated situation exists in magnetite. The proportions of Mg^{2+} to Fe^{2+} and of Al^{3+} to Fe^{3+} vary widely, whereas the proportions of Mn^{2+} to the other divalent cations and of Mn^{3+} to the other trivalent cations vary relatively slightly. However, in each case the sum of the relative numbers of divalent and trivalent cations is constant. Reference to Figure 1 immediately suggests a possible reason for these relations. The atoms Mg^{2+}, Fe^{2+}, and Mn^{2+} are similar in size and the atoms Al^{3+}, Fe^{3+}, and Mn^{3+} are likewise similar in size but distinctly smaller than those of the first-mentioned group. From what has already been said about the control of mineral structures by the sizes of the constituent atoms, it may be inferred that atoms of similar sizes can fit in the same positions.

The control upon isomorphism by the sizes of atoms was recognized about twenty-five years ago (1926) by Goldschmidt. On the basis of a study of the ranges in composition of a great many minerals, he concluded that atoms having radii within approximately fifteen per cent of one another could fulfill one another's function in mineral structures, or, as it is more commonly stated, "substitute" for one another. Atoms that differ by more than fifteen per cent in radius generally cannot substitute for one another so extensively; isomorphism is limited in such cases.

Although the size of atoms appears to be the prime factor controlling the degree to which isomorphism can take place, other factors must also be considered. For instance, the electronic and nuclear configurations of atoms affect isomorphism by their control on the nature of the bonding forces. In general, the greater the similarity in bonding properties the more completely can atoms substitute for one another.

The degree of isomorphism possible in some minerals may be affected by the nature of the atomic arrangement. Some arrangements of atoms seem to have considerable structural "resiliency." Certain positions in such structures may be occupied by atoms varying considerably in size without distorting the structure, though they may cause it to become unstable. Isomorphism in such minerals can be more complete than would be predicted from the fifteen per cent rule.

The environment in which minerals form also controls the degree of isomorphism. Temperature is especially important because high temperatures appear to cause a "loosening" of atomic structures so that atoms differing more than fifteen per cent in radius can substitute for one another to a far greater extent than is possible at lower temperatures. This is strikingly shown by potash and soda feldspar. In fact, a few minerals ordinarily exhibit only slight isomorphism simply because they happen to form almost exclusively in environments where temperatures are relatively low. For example, natural pyrargyrite and prousite apparently form at such low temperatures that little isomorphism is possible between the Sb and As atoms (See Figure 1). On the other hand, synthetic pyrargyrite and prousite prepared at a few hundred degrees Centigrade can show complete isomorphism. Temperature may also influence the degree of isomorphism by slightly modifying the relative sizes of atoms.

Pressure may affect isomorphism, but to a considerably lesser degree than temperature, by modifying slightly the relative sizes of atoms.

A further point in regard to valence must also be mentioned. In the examples taken to illustrate isomorphism, the atoms substituting for one another were of the same valence. Actually, atoms taking part in isomorphism need not be of the same valence. The only valence requirement is that electric neutrality be preserved for the whole crystal. Thus, if a trivalent cation is available it can substitute for a

divalent cation if similar in size and if the extra positive charge can be compensated by substitution of an ion elsewhere in the structure involving the addition of a negative, or the substraction of a positive, charge. The latter case is well illustrated by plagioclase, in which Ca^{2+} can substitute for Na^{+} because a complementary substitution of Al^{3+} for Si^{4+} can also be made to preserve electric neutrality. This type of isomorphism is of great importance in the silicates and accounts for much of the complexity in composition of the common rock-forming minerals.

Before we leave the subject of isomorphism, a word about terminology is, perhaps, in order. In the first place, "isomorphism" has two different meanings, depending upon who uses it. Mineralogists generally use the term in the sense the writer uses it above, but chemists and physicists generally speak of isomorphism as synonomous with isostructuralism. Other terms used to refer to isomorphism in the mineralogic sense are "solid solution" and "mixed crystal." The term "mixed crystal," however, is a poor one to denote isomorphism in general, particularly when the term is intended to imply, as it does in most mineralogic texts, the intercrystallization of two or more isostructural species of minerals. One type of isomorphism may be thought of as resulting from such "mixing" of different crystalline phases on an atomic scale, but a more general type results from the mixing of atoms in equivalent structural positions in a single crystalline phase. The usage of the term "mixed crystal," should therefore be restricted to the special variety of isomorphism implied by the literal meaning of the term.

Isostructuralism

Isostructuralism (the "isomorphism" of many physicists and chemists) requires atomic arrangements which are similar in form though not necessarily in scale. The controlling factor is the radius ratio. As an illustration, Table 4 lists various fluorides and oxides and their radius ratios. Those compounds in Table 4 which have radius ratios equal to or greater

than 0.77 have a fluorite-type structure, whereas those which have radius ratios equal to or less than 0.68 have a rutile-type structure. Thus two isostructural types are represented. In the case of simple compounds such as these, we could have predicted the structures with the aid of Table 1. As this table shows, 0.732 is the limiting ratio between a cubic and an octahedral type of arrangement.

TABLE 4

Radius ratios of simple fluorides and oxides in relation to isostructural groups.

Compound	Radius Ratio	Isostructural group
BaF_2	1.08	
SrF_2	0.95	Fluorite-type
ThO_2	0.83	(8 anions around each
CaF_2	0.80	cation)
UO_2	0.78	(4 cations around each
CdF_2	0.77	anion)
TeO_2	0.68	Rutile-type
MnF_2	0.68	(6 anions around each
MgF_2	0.59	cation)
TiO_2	0.49	(3 cations around each anion)

We cannot, however, apply the limiting ratios of Table 1 exactly because they were calculated on the basis of rigid and perfect spheres of constant size. Real atoms are not rigid spheres; probably they often are not perfect spheres, and they vary slightly in size depending upon the environment. Nonetheless, the general principle is clear that assemblages of atoms having similar relative sizes also have similar structures.

Polymorphism

An understanding of isostructuralism clears the way for an appreciation of one of the most important causes of polymorphism. Consider, for example, a simple CA_2 type of compound having a radius ratio only very slightly less than one of the limiting ratios listed in Table 1--say 0.732. It is not difficult to infer that although a rutile-type of structure will be favored for such a compound, it will be favored only slightly more than a fluorite-type of structure. Moreover, the closer the radius ratio approaches the limiting ratio, the less is the rutile-type of structure favored over the fluorite-type. In such cases, the delicate balance favoring one type of structure may be sufficiently counterbalanced under special conditions to give rise to the other instead. Some of the special conditions that can lead to such change in structure are (1) extremes of temperature or pressure, causing changes in atomic size, shape, or bonding properties (2) substitution of even a few atoms of such size or sizes as to cause the average radius ratio of the compound to be nearer to or on the other side of a limiting ratio, and (3) certain effects--not well understood but probably energetic in nature--due to the presence of acids or bases or organisms.

Most minerals are more complicated than the simple binary compounds used as examples. Generally we cannot predict so easily which minerals will show isostructuralism or polymorphism. The radius ratio principle is an extremely useful concept nonetheless.

The carbonate group of minerals affords excellent illustrations of both isostructuralism and polymorphism. If we list, as in Table 5, the common simple carbonates in order of the size of their cations, (See Figure 1), we note that those composed of cations equal to or larger than Ca^{2+} belong to the familiar isostructural series of the orthorhombic carbonates. Those composed of cations equal to or smaller than

Ca^{2+} belong to the rhombohedral series. Evan an elementary student can easily appreciate on this basis why the carbonates of Mn, Zn, Fe, and Mg are so similar to one another in crystallography but so different from those of Ba, Pb, and Sr.

TABLE 5

Simple carbonate minerals arranged in order of decreasing size of cation.

$BaCO_3$	witherite	
$PbCO_3$	cerussite	Orthorhombic
$SrCO_3$	strontianite	Group
	aragonite	
$CaCO_3$	----------	
	calcite	
$MnCO_3$	rhodochrosite	
$FeCO_3$	siderite	Rhombohedral
$ZnCO_3$	smithsonite	Group
$MgCO_3$	magnesite	

The dimorphism of $CaCO_3$ suggests that the size of Ca is such that the rhombohedral type of structure is ordinarily favored but that it is so close to the limit that the orthorhombic type of structure may be favored under special conditions. Thus, we find calcite to be the ordinary form of $CaCO_3$, whereas aragonite commonly is the stable form (a) at higher temperatures, under surface pressures, (b) in the presence of large cations such as Pb^{2+}, Sr^{2+}, Ba^{2+} (c) in the presence of certain anion radicles such as SO_4^{2-}, or (d) under the influence of certain organisms such as molluscs.

TABLE 6. Structural characteristics of silicates.

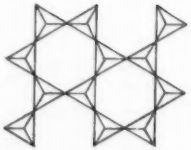
Tetrahedral grouping	Descriptive Name	Relative numbers of atoms	Electric charges +	−	Formula of group (Lowest multiple)	Representative mineral
	separate tetrahedra	1 Si 4 O SiO_4	4	8 4−	$(SiO_4)^{4-}$	olivine $(Mg,Fe)_2SiO_4$
	double tetrahedra	2 Si 7 O Si_2O_7	8	14 6−	$(Si_2O_7)^{6-}$	thortveitite $Sc_2Si_2O_7$
	chain	1 Si 2 + 2/2 O SiO_3	4	6 2−	$(SiO_3)^{2-}$	pyroxene $(Mg,Fe)SiO_3$
	three-membered ring	3 Si 9 O Si_3O_9	12	18 6−	$(SiO_3)_3^{6-}$	benitoite $BaTiSi_3O_9$

six-membered ring

6	Si	24
18	0	36
Si_6O_{18}		12-

$(SiO_3)_6^{12-}$

beryl
$Be_3Al_2Si_6O_{18}$



sheet

1	Si	4
1 + 3/2	0	5
$SiO_{5/2}$		1-

$(Si_2O_5)^{2-}$

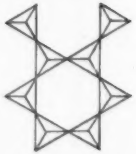
talc
$Mg_3Si_4O_{10}(OH)_2$

framework

1	Si	4
4/2	0	4
SiO_2		0

$(SiO_2)^0$

quartz
SiO_2



double chain or band

2	Si	8
4 + 3/2	0	11
$Si_2O_{11/2}$		3-

$(Si_4O_{11})^{6-}$

amphibole
$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$

Silicates

Inasmuch as the silicates are the most complex (and the most important) minerals encountered by elementary students, it is especially valuable to see how the application of crystallo-chemical principles aids in the understanding of this particular group. The following discussion is intended to be only an extremely general introduction to the nature of silicates. More detailed information can be obtained from other sources, such as Kraus, Hunt, and Ramsdell (1951); Winchell (1942); Stillwell (1938); Evans (1948); Hatch, Hatch, and Wells (1949); and Bragg (1937). Furthermore, it should be understood that any consideration of the silicates can be fully appreciated only with the aid of structural models. One simple and convenient type has recently been described (Henderson, 1950).

In most environments, Si forms discrete radicles with O because the electronic structures of these atoms cause the bond between them to be unusually strong. These radicles have a particular composition and shape because the relative sizes of the atoms permit four O^{2-} to fit around each Si^{4+} and form the so-called "silicate tetrahedron" $(SiO_4)^{4-}$. X-ray studies show that this silicate tetrahedron is the fundamental unit of construction of all silicate minerals.

The construction of the silicates is complicated, however, by a sort of "polymerization" in which the fundamental tetrahedral units can be joined into many different kinds of tetrahedral groups. This "polymerization" causes much of the complexity in the composition and physical properties of the silicates. It occurs because more than one tetrahedron can be joined by sharing one or more O^{2-}. Table 6 shows the ways in which the tetrahedra are joined. The basic architecture of each species of silicate crystal is controlled by tetrahedral groups of one of the types shown repetitively arranged and generally snugly

packed together.[1] The remainder of each crystal is filled out by cations (and in some cases additional anions), which fit in the interstices between the groups and bond them together.

It is obvious that the different kinds of tetrahedral groups offer a basis for a fundamental classification of silicates. In fact, this is the basis for all modern classifications. Even an elementary knowledge of the different groups enables one to predict, or at least appreciate, a great deal about the properties of silicates. For example, minerals constructed with chains of tetrahedra will have a major part of their composition based on some multiple of $(SiO_3)^{2-}$ (See Table 6). The kinds and relative numbers of the cations completing the composition will be controlled by the net electric charge of each chain (2- for each tetrahedron) and the number and sizes of the interstices between the chains. Reasonably good predictions of the kinds and numbers of cations could be made with the aid of models of chains. In the most common type of chain silicate, the pyroxenes, it would be found that cations having sizes between those of Ca and Mg would fit best in the interstices and that cations as small as Al could also fit in them to a limited degree. Fe^{2+} falls in the first category (See Figure 1), and Fe^{3+} in the second. Other atoms satisfying the size requirements are less common. It might therefore be guessed that the general composition of the pyroxene family could be given crudely as $(\underline{Ca},\underline{Mg},\underline{Fe}^{2+},Al,Fe^{3+})SiO_3$. (The underlining indicates relative abundance.)

Actually, of course, two chief kinds of pyroxene are recognized: (1) orthopyroxene (enstatite-hypersthene), $(\underline{Mg},\underline{Fe})SiO_3$, and (2) clinopyroxene (diopside-hedenbergite-augite), $Ca(\underline{Mg},\underline{Fe}^{2+},Fe^{3+},Al)(\underline{Si},Al)_2O_6$. These two types occur because the chains can be

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[1] A few silicates, such as idocrase, contain more than one kind of group.

arranged in slightly different ways (cf. Bragg, 1937, p. 187). In orthopyroxene, the chains are arranged so that the interstices are all approximately similar to Mg in size. In clinopyroxene, there are alternate pairs of rows of interstices parallel to the chains, which have sizes approximately the same as Ca and Mg respectively.

The type of tetrahedral grouping also greatly affects the physical properties of silicates. Referring again to the pyroxenes as an example, one might anticipate that a prismatic type of crystallographic habit would be favored parallel to the length of the chains--as indeed it is. Moreover, any cleavage present should also be prismatic because the bonds within the chains are stronger than those between the chains. (The prismatic cleavage of pyroxene is well known.) Even the cleavage angle in pyroxene can be predicted by consideration of the cross-sectional shape of the chain (cf. Bragg, 1937, p. 196). Similar reasoning can be applied to the crystal habit and cleavage of other silicates.

Consideration of the nature of the tetrahedral groups is the basis for an understanding, not only of the composition, crystallography, and cleavage of silicates, but also of many other of their properties, such as differential hardness, ease of melting, viscosity in melts, optical properties, and relative speed of reaction.

Relatively little is yet known about the factors that favor the formation of a particular kind of tetrahedral group. The information available, however, suggests that the environment in which a silicate forms is at least partly a controlling factor. The common rock-forming ferromagnesian silicates--olivine, pyroxene, amphibole, and biotite (Bowen's reaction series)--apparently represent an example of this kind of control. These minerals form in igneous rocks approximately in the order listed, suggesting that olivine crystallizes at the highest temperature and

that the succeeding minerals crystallize at progressively lower temperatures. As shown in Table 6, olivine has the separate-tetrahedra type of grouping; the pyroxenes have chains; the amphiboles, double chains; and biotite has a sheet structure. Here temperature seems to have been a controlling factor in determining the arrangement of the tetrahedra. Actually, the formation of a given kind of tetrahedral grouping is probably a response to extremely complex interplay of factors of a thermodynamic nature which control the relative number of available atoms taken up by Si as against those taken up by other cations. Separate tetrahedral groups probably are favored where sufficient O is available and where tie-up with Si is favored. On the other hand, tetrahedral groups composed of fewer O per Si (cf. Table 6) probably are favored where insufficient O are available or where tie-up of O to Si is not so strongly favored.

One other cause of complexity in silicates needs brief consideration. This is the special role of Al in silicate structures. Although the radius ratio of Al to O is 0.43 and a 6-fold coordination would be expected, the value is close enough to the upper limit of 4-fold coordination (0.414) so that Al can, under special conditions, particularly those of high temperature, fit within tetrahedra of $(AlO_4)^{5-}$ analogous to those of $(SiO_4)^{4-}$. As a result, Al can substitute to a limited extent at least for Si as well as for cations such as Ti, Fe^{3+}, Mg, and Fe^{2+}. This obviously opens the way for a tremendous variety of composition because each substitution of Al^{3+} for Si^{4+} must be compensated elsewhere in the structure by a complementary substitution which will add another positive charge or remove a negative charge. Plagioclase has already been cited as an example of this kind of substitution. In fact, all the "framework" silicates, other than the SiO_2 minerals, are possible only because of this property of Al. As shown by Table 6, "frameworks" constructed entirely of silicate tetrahedra are electrically neutral and no other constituents can be added. However, if Al is present in some of the tetrahedra rather

than Si, the framework gains a negative charge for each such substitution. Inasmuch as the frameworks are relatively open structures, large cations such as K, Na, Ca, and Ba can fit in and neutralize the negative charges of the framework. Minerals such as the feldspars, feldspathoids, and zeolites are constructed in this way.

The platy minerals also offer an excellent illustration of the dual role that Al can perform in the construction and composition of the silicates. Talc, for instance, is constructed with double sheets of silicate tetrahedra and has the composition $(\underline{Mg},Fe)_3Si_4O_{10}(OH)_2$. However, if one of every four Si in the tetrahedra is replaced by an Al, each such unit of the sheets will have an extra negative charge. This may be compensated by the appearance of K atoms filling large holes between pairs of double sheets. The result is a new mineral--biotite[1], $K(\underline{Mg},\underline{Fe})_3(AlSi_3)O_{10}(OH)_2$. The composition of biotite is actually more complicated than that of this idealized formula since generally more than one quarter of the Si are replaced by Al and additional compensating substitution must take place elsewhere in the structure.

The writer has attempted in the foregoing pages to show the importance of crystallo-chemical principles for an understanding of mineralogy at even an elementary level. A few simple examples have been cited to show how these principles, particularly the concept of "atomic size," aid greatly in the explanation of atomic arrangements, isomorphism, isostructuralism, polymorphism, and the properties of silicates. Many additional examples could be given. It is hoped, however, that even this brief

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[1]Muscovite, $KAl_2(AlSi_3)O_{10}(OH)_2$, has a similar relationship to the talc-like mineral pyrophyllite, $Al_2Si_4O_{10}(OH)_2$.

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A SEMESTER COURSE IN INVERTEBRATE PALEONTOLOGY[1]

Charles L. Bieber
DePauw University

Invertebrate Paleontology as given at DePauw is a four-hour, one-semester course offered in alternate years. Classes meet two hours per week for lecture and discussion. Two periods of three hours each are spent in the laboratory. A three-hour course in stratigraphy follows in the second semester, in which emphasis is placed on stratigraphic paleontology.

The course is designed to be both broad and deep. A difficulty seems to be that for majors it is too broad and not deep enough, while for non-majors it is both too broad and too deep. In the past semester six students were enrolled in the class, all majors. The eventual hope is a course which will attract--besides geologists--zoologists, economists, and even serious liberal arts students.

The writer feels that at the undergraduate level the student should develop with as broad a base as possible. However, when he decides to take a course such as paleontology, he should expect to dig in for himself with the teacher acting as a guide. He should expect that some memory work will be included and that considerable reading will be demanded.

The text which has been used for several years is "Invertebrate Paleontology" by Twenhofel and Shrock. The text is thorough, but perhaps too detailed for the average undergraduate. More students might be attracted by use of a text similar to Shimer's "An Introduction to the Study of Fossils."

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[1]Paper read before the Midwest Section, Association of Geology Teachers, March 30, 1951.

The course follows the orgainization used in the text. The traditional sequence, Protozoa through Arthropoda, is followed. Two to three class sessions are used for each phylum. In the study of body structure hard skeletal parts are emphasized. Considerable time must be spent on the zoological aspects of the subject because of the lack of background by the majority of the students. This means that ecology and evolution suffer somewhat from lack of time.

The type of student that has been thus far attracted to the course has been able to assimilate the terminology. The majority of the terms in italics in the text are committed to memory. A minor percentage of the allotted time is spent in class drill and recitation, which is designed to spur the student in his daily assignments.

Outside readings are assigned to acquaint the student with some of the outstanding workers in the different phyla. Much of the class discussion centers around the outside assignments.

The opening class hour on a phylum is given to the review of a type animal. Some diagram work is presented, but prepared charts and line diagrams have not been acquired by the department. A fossil representative, or the entire animal preserved in plastic, is at hand for each student. Morphology, mode of preservation, environment, food, and growth are reviewed.

The second class period takes up taxonomy. The part which seems to be desirable for the student to learn is pointed out to him. A list of common fossils for the phylum is given with remarks about each. The ones to be memorized by genus and horizon are made known.

The third class hour reviews the phylum, follows it through its geologic history, and invites discussion of work by various authors. The discussions in the

early part of the semester are not very successful, but they improve as the student gains mastery of terminology and principles.

Because of the too great tax on the memory if the entire semester's work were to be covered in a single examination, three or four examinations are held during the course. Two or more phyla are covered at one time in a one-hour examination. Questions usually cover terminology, environmental factors, evolution, mode of fossilization, and recognition of ten to fifteen guide fossils. These examinations conclude the detailed work on their respective sections of the course. The final examination covers only such material as has not previously been covered, plus one or two essay questions on general aspects of the course.

No laboratory manual is used. The instructor makes up a work sheet each week which covers two laboratory periods (six hours) of work. A laboratory time is scheduled, but the actual work is carried out more or less at the students' convenience. This helps to avoid conflict with chemistry, physics, and mathematics courses which are demanded of the geology major. (It may be added that this arrangement increases the burden on the teacher.)

Work in the laboratory runs parallel to the work in the class. For example, in the study of Protozoa the student mounts a few samples of foraminifera picked by himself from foraminiferal sands. He attempts identification of the specimens on his slide. A slide of 100 common forams with identifications is studied. A slide of ten to fifteen forams is given each student for identification. Microscope work is emphasized throughout. Shales, cuttings, and insoluble residues are studied with the microscope in various laboratory periods during the semester. Laboratory work with the corals, bryozoans, and cephalopods calls for grinding of specimens, with examination of structures under the microscope.

The guide fossils are studied during laboratory time. Drawing work is optional, although the student is expected to keep a notebook. Approximately 150 fossils are learned during the semester.

A semester project of collecting, identifying, and photographing fossils from an assigned Mississippian formation is carried on as a part of the laboratory work.

One all-day field trip is normally taken. It may go north into the Silurian and Devonian, or south to the Ohio River for Ordovician to Mississippian fossils. An alternative half-day trip is taken in the Greencastle area. In addition, student field projects are assigned: methods of fossilization are studied directly in one of the local quarries; Mississippian cherts are collected for a study of the genesis of the cherts; Mississippian bryozoans are collected and ground; and Pennsylvanian black shales are collected west of Greencastle.

The course as now given is rather heavy for the average undergraduate. However the majors demand such a course, and since the number of major students averages from ten to twelve, standards will remain essentially as outlined herein.

ELEMENTARY PALEONTOLOGY AS TAUGHT AT IOWA STATE COLLEGE

Leo A. Thomas
Iowa State College

A search through the catalogs of thirty universities and colleges throughout the United States indicates that at eight institutions, elementary paleontology is offered as a half-year course, whereas the remaining institutions offer it as a year sequence. The catalog descriptions further indicate that the two-semester course consists of systematics in the first half year followed by stratigraphic paleontology in the second. These courses are mostly offered at the upper-class level, and carry from three to six hours' credit per semester, with three or four credit hours being the most common. Generally, the courses involve either two lectures and one laboratory per week or three lectures and one laboratory. In almost all cases the sole prerequisite is elementary historical geology. Several institutions permit substitution of zoology or botany.

At Iowa State College we require for the geology major only one quarter of elementary paleontology, which carries four hours' credit. There are two hours of lecture and six hours of laboratory per week. It is possible for the student who so elects to substitute a three-quarter course which follows a rather unusual plan. This course has been designed to embody most of the subject matter of comparable courses given at other institutions, but emphasis has been directed by two principles. First, we recognize that only a few of the students who take the course will ever select paleontology as a major field of endeavor. Second, we believe that those students who may eventually use paleontology are most apt to use it as a tool for stratigraphic work, and consequently should study fossils mainly in relation to their associated rocks. We favor, therefore, an attempt to integrate systematic and stratigraphic paleontology.

During the first portion of this course the lecturing is orthodox, dealing with classification, fossil structures, phylogeny, and the outstanding literature and names of workers associated with the various phyla and classes of animals.

In the accompanying laboratory exercises, we are not primarily interested in the student's learning the names and ranges of a lot of genera and species (most of which he will forget), but rather in his acquiring the techniques of analyzing the skeletal characters that are used for identification and knowing how to "run down the specimen." A portion of our brachiopod exercise will be used to show how we try to accomplish this objective.

The student is supplied with a set of labeled diagrams showing most of the taxonomically important internal structures. The diagrams are supplementary to a display of actual specimens that exhibit both internal and external features. When the student demonstrates a knowledge of these structures he is given a completely unknown specimen to section, make sketches of, label, and reconstruct in three dimensions. Pertinent literature is supplied and the student is required to identify his specimen at least to the genus level. The student also learns how to seek out additional literature by means of the standard bibliographies.

Emphasis is also placed on occurrence, collecting, and preparation of specimens for study. One or two collecting trips are used to demonstrate that fossil assemblages occur in distinct zones and that detailed stratigraphic analysis requires that specimens be collected as assemblages. The preparation of stratigraphic logs and the technique of sampling and labeling of collections are given thorough consideration

Emphasis is given likewise to the preparation of specimens for study. This includes the washing of sediment samples for micro-organisms, etching of

acid-resistant specimens, camera lucida and cellulose peel reproductions, and preparation of thin sections.

The second portion of the course is more strongly directed toward stratigraphic paleontology. The laboratory work is concerned, first, with the study of labeled index fossils and index assemblages, and second, with the analysis of unknown assemblages. In working with unknown assemblages the student is expected to search the literature, make specific identifications, and an age determination.

The following is a general outline of the lectures for the course. A few selected references are also given as a guide to the type of outside reading required of our students. Many other excellent references are available, any one of which might be substituted for ones in my list, but space does not allow a more adequate treatment.

COURSE OUTLINE

1. Taxonomy.
   The Linne' method; detailed classification.
   International rules of nomenclature.
   Procedure for the proposing of new names; regulations governing priority of names, type specimens, etc.

   Reference:

   Schenck, E. T. and McMasters, J. H., "Procedure in Taxonomy, including a Reprint of the International Rules of Zoological Nomenclature with Summaries of Opinions Rendered to Present Date," revised edition, Stanford Univ. Press (1948) 93 pp.

2. Paleontologic correlation.
   Need for correlation.
   History: contributions of Smith, d'Orbigny, H. S. Williams, Ulrich, etc.

Methods of correlation: guide species, percentage of like species, etc.

References:

Galloway, J. J., "Methods of Correlation by means of Foraminifera," Amer. Assoc. Petrol. Geol., Bull., vol. 10, No. 6 (1926) pp. 562-567.

Ulrich, E. O., "Revision of the Paleozoic Systems," Geol. Soc. Amer., Bull., vol. 22 (1911) pp. 469-473.

3. Paleontologic zonation; time-stratigraphic terminology.

History of the time-stratigraphic concept.

Terminology: epibole, zone, stage, faunizone, etc.

Synchronous vs. contemporaneous units.

References:

Arkell, W. J., Jurassic System in Great Britain, Oxford, Clarendon Press, 1933, pp. 1-37.

Kleinpell, R. M., "Miocene Stratigraphy of California," Amer. Assoc. Petrol. Geol., Spec. Publ., vol. 18 (1938).

Lowenstam, H. A., "Biostratigraphic Studies of the Niagaran Inter-Reef Formations in Northeastern Illinois," Ill. State Mus., Scientific Papers, vol. 4 (1948), pp. 1-142.

4. Sedimentary facies and paleontologic correlation.

History and meaning of the term "facies."

Transgressive and regressive fossil environments.

References:

McKee, E. D., "Cambrian History of the Grand Canyon Region," Carnegie Inst. of Washington, Publications, No. 563 (1945).

Caster, K. E., "The Stratigraphy and Paleontology of Northwestern Pennsylvania: Part I, Stratigraphy," Bull. Amer. Paleontology, vol. 21, No. 71 (1934), pp. 19-36.

Longwell, C. R. (chairman), "Sedimentary Facies in Geologic History," a symposium, Geol. Soc. Amer., Memoirs, No. 39 (1949).

Lowman, S. W., "Sedimentary Facies in the Gulf Coast," Amer. Assoc. Petrol. Geol., Bull., vol. 33 (1949), pp. 1939-1997.

5. Ecology.

Zoologic methods of analysis; most organisms rigidly confined by their environment.

Difficulty of reconstructing fossil environments.

References:

Natland, M. L., "The Temperature and Depth Distribution of Some Recent and Fossil Foraminifera in the Southern California Region," Univ. of Calif., Scripps Institute of Oceonography, Bull. Tech. Series, vol. 3, No. 10, (1933), pp. 225-230.

Scott, G., "Paleoecological Factors Controlling the Distribution and Mode of Life of Cretaceous Ammonoids in the Texas Area," Jour. Paleo., vol. 14 (1940), pp. 299-323.

Elias, M. K., "Depth of Deposition of the Big Blue (Late Paleozoic) Sediments in Kansas," Geol. Soc. Amer., Bull., vol. 48 (1937), pp. 403-432.

6. The species concept.

Change from a static to a dynamic concept: illustrations from Linne', Agassiz, Cuvier, Darwin, etc.

Morphologic vs. phylogenetic species.

Temporal species.

Species and sub-species to express a stratigraphic concept.

References:

Burma, B. H., "Studies in Quantitative Paleontology: I," Jour. Paleo., vol. 22, No. 6, (1948), pp. 725-761.

Burma, B. H., "Studies in Quantitative Paleontology: II," Jour. Paleo., vol. 23, No. 1, (1949), pp. 95-103.

Weller, J. M., "Paleontologic Classification," Jour. Paleo., vol. 23, No. 6, (1949), pp. 680-690.

Bell, W. C., "Stratigraphy: a Factor in Paleontologic Taxonomy," Jour. Paleo., vol. 24, No. 4, (1950), pp. 492-496.

7. Evolution.
   What evolution means.
   Early history of the concept.
   Macro- vs. micro-evolution.
   Relation of evolution to periods of orogeny.
   Neo-Lamarckian and neo-Darwinian concepts.
   References:

Mayr, E., Systematics and the Origin of Species, Columbia Univ. Press, Biological Series, (1947) 334 pp.
Simpson, G. G., Tempo and Mode in Evolution, Columbia Univ. Press (1944) 237 pp.
Huxley, J., Evolution, the Modern Synthesis, Harpers (1933) 645 pp.

8. Synthesis.
   Correlation of fossil assemblages largely a correlation of environments.
   Resulting difficulties.
   Necessity for balanced evaluation of evolutionary and environmental factors.

A MODIFIED TILTING BLACKBOARD FOR GEOLOGIC INSTRUCTION

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H. S. Palmer[2] has described a convenient blackboard teaching aid for the demonstration of angular unconformities, transgressive and regressive overlap, tilted lake basins, and other structural features. It consists of an 18 by 48 inch piece of Masonite, or other hard wallboard, coated with blackboard paint on one side, and fitted with a pair of eye-screws at the upper corners so that it can be suspended in front of the regular blackboard. The auxiliary board can be tilted to any desired position by changing the lengths of the suspension cords. Palmer's apparatus is well adapted to the demonstration of features in which rotation of the auxiliary blackboard about a central point produces the desired result. However, a completely satisfactory representation of the development of transgressive overlap (onlap) and regressive overlap (offlap) is not attainable unless minor modifications are made to the suspension mechanism of the board. It is highly desirable that any graphic method for demonstrating these features should show the relationship of each sedimentary unit to sea level at the time of deposition. Also, for clarity of demonstration, the youngest sedimentary unit should be drawn last, yet retain the proper contact relationships with the units below.

Various methods of suspending the board will produce the correct cross-sectional picture, but most of

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[1]Transferred to the Carter Oil Company, Research Laboratory, Tulsa, Oklahoma, since preparation of this article.

[2]H. S. Palmer, "A Tilting Blackboard for Geologic Instruction," Science, October 27, 1933, p. 388.

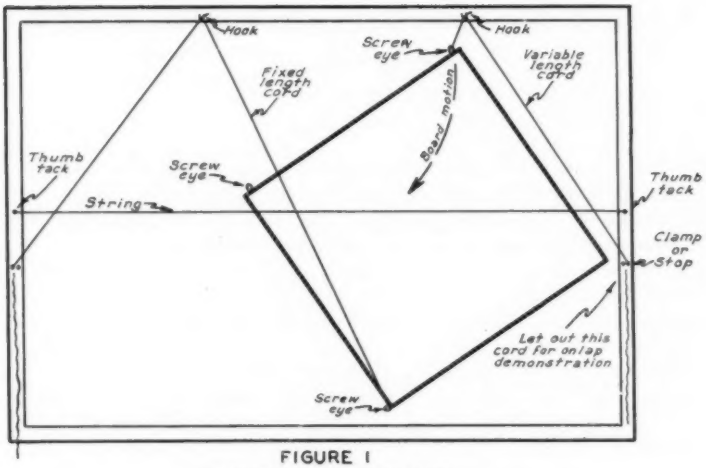

FIGURE 1
ASSEMBLY DIAGRAM
AND
STARTING POSITION FOR ONLAP DEMONSTRATION

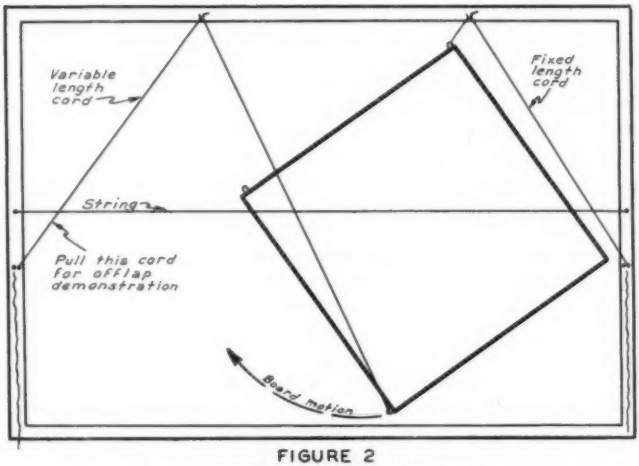

FIGURE 2
ASSEMBLY DIAGRAM
AND
STARTING POSITION FOR OFFLAP DEMONSTRATION

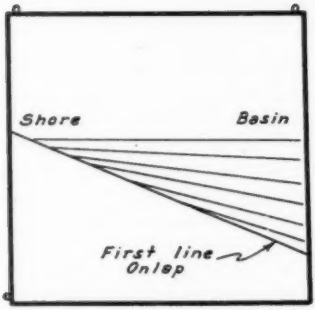

DIAGRAM OF PATTERN PRODUCED
FOR DEMONSTRATION OF ONLAP

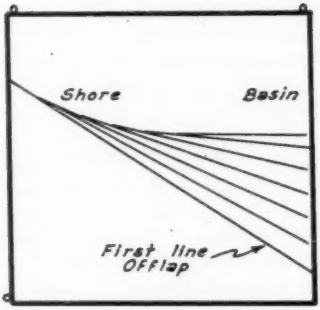

DIAGRAM OF PATTERN PRODUCED
FOR DEMONSTRATION OF OFFLAP

FIGURE 3

these require a reverse order of "deposition"--a circumstance confusing to the elementary student.

The following modification of Palmer's device makes for a clearer demonstration of onlap and offlap: Use an auxiliary board more nearly square than that used by Palmer. A board 40 inches wide and 48 inches long is used by the writer at the University of Wyoming. Attach two eye-screws to the top edge at the extreme corners. (Only one of these is used to demonstrate onlap and offlap. The other will be useful, however, in showing the development of unconformities, etc.) Place an additional eye-screw on the left vertical edge at the lower corner. Suspend the auxiliary board from the top of the permanent blackboard as indicated in Figure 1. The supporting cords are knotted at intervals along their free ends, the knots being used as "stops" when the cord is slipped between a pair of nails driven into the permanent board frame. As an alternative to nails and knots, a common heavy laboratory spring clamp may be used to hold the cord, the loop of the clamp handle being slipped over a nail in the frame.

At a convenient height across the permanent blackboard and in front of the movable board, stretch a white string horizontally. Hold it in place with thumbtacks. This string is used to represent sea level.

For the demonstration of transgressive overlap (onlap), pull the right end of the suspended board up as far as it will go. Draw a line on the auxiliary board along the string. Continue lowering the right side of the board (basin subsidence), and marking successive positions of the sea level string, until the top of the board is horizontal. After the first line has been drawn, do not cross over it to the left when adding new "units". The rotation of the board around the lower left corner, in addition to a left-swinging pendulum motion, produces the characteristic pattern of transgressive overlap as shown in Figure 3 (top). The "basin of deposition" appears at the right

side of the board.

For the demonstration of regressive overlap (off-lap), the upper right corner is used as the pivot support and the cord attached to the lower left corner is varied in length. The left corner is first lowered until the board hangs at about 45 degrees from the horizontal (Figure 2). Draw the first line with the board in this position. In the same manner as before, the board is now raised in increments of several inches by pulling on the cord attached to the left side. Draw a horizontal line (without crossing to the left of any previous line) each time the board is moved. Figure 3 (bottom) shows the result. The "basin of deposition" again appears on the right. Each bed is "deposited" in proper sequence and in correct relationship to other beds.

Construction of this device requires only a few minutes after the materials have been assembled. About five minutes are required before a class meeting to hang the board and stretch the "sea level" string. The class time required for the demonstration is far less than that used in attempting to correctly draw and explain the principle on a stationary board. The student seldom forgets these two geologic processes after a graphic demonstration.

PREPARATION OF TEACHERS FOR EARTH SCIENCE EDUCATION IN THE GRADES[1]

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I am a strong believer in the teaching of earth science in our public schools. We are told "the world is with us." Though the author of these words had, perhaps, a slightly different idea in mind, the world is with us and it is necessary to know the world--and to know it early if we are to know it well. Our education in this regard should begin even before we reach the secondary school level. It is the responsibility of our teachers in the elementary grades to introduce us to earth science. Why in the elementary grades? Because it is at this stage in the educational process that youngsters are most receptive. Children of six, seven, and eight are brimming over with questions about the "how" and "why" of things they see about them.

It must be remembered, too, that the majority of young people do not go on to college. Many do not even finish high school. Is earth science education to be the privilege of only those few who reach the college level?

The grade school teacher, in order to give effective instruction in earth science, must have been effectively taught. Many of the institutions where such teachers are trained have no geology in their curricula. This is a situation which should be

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[1]Paper presented at the Second Conference on the Teaching of Earth Science in the Secondary Schools, Cambridge, Mass., March 16-17, 1951.

rectified. In the meanwhile, however, the resourceful teachers-college instructor may find opportunity to introduce geology in courses of another name. I should like to illustrate this point by a brief description of my own experience as a teacher at Salem State Teachers College in Massachusetts.

When I arrived in September, 1950, it was to assume a position in the Department of Geography. I found that my program consisted of courses in Elements of Geography, Economic Geography, Methods of Teaching Geography, and "Global Geography." Syllabi leaving little leeway in the material to be covered were provided for the first three courses. For the last course there was no syllabus. The course was listed as a freshman elective. I inquired of my predecessor and was informed that the course could cover whatever I wanted, so long as it did not duplicate material taught by other members of the department.

What a golden opportunity! "Global Geography" quickly became a course in earth science. Forty-five unsuspecting freshmen elected it. I assigned no one textbook, but encouraged them to seek information from a number of the less technical ones. The work was laid out to cover certain broad topics: the earth as a planet; its internal structure and surface processes; earth materials; topographic and geologic maps; continental evolution; the weather.

I found myself faced with many problems. Salem State Teachers is a commuter's college, with many students who come from considerable distances. Quite a few work after school. Their academic programs are crowded. Regular laboratory periods were, therefore, out of the question. I felt, however, that some field trips and laboratory work were essential. Necessity is the mother of invention. I assigned laboratory work on rocks and minerals to be done at odd hours. Carefully labelled specimens were placed on a table for study. The students came, singly or in groups of ten to fifteen, and mulled

over them. They learned partly by discussion among themselves. By the end of the course they were able to pass an identification test covering forty minerals and thirty-five rocks. Laboratory exercises on topographic maps were arranged as homework.

Field trips were limited to areas within five miles of the school. During the year the class visited no less than eight different localities. On each trip attention was centered on one or two features related to material currently under discussion in the classroom. Travelling in private cars we were able to cut down the time per trip to less than one hour. Thus required field trips could be scheduled for regular class hours. In addition three longer optional trips were planned for vacation periods.

In a teachers college it is necessary not only to instruct but also to suggest methods by which the instruction may be passed along to others. Most of my students expected to teach on the pre-high-school level. For the first four grades I suggested a variety of simple projects in earth science: measuring seasonal variations in the sun's elevation at noon by means of a shadow stick; finding directions with a compass; observing evidences of work done by running water in the school yard after a rainstorm. By making and recording their own observations and by reasoning about what they have observed even very young children may begin to understand and apply scientific procedures.

For the upper grades I suggested various simple classroom experiments: solution of salt by water, and the precipitation of this same salt as a result of evaporation; the ability of water in motion to hold solid matter in suspension, and the deposition of this suspended matter when the water is allowed to come to rest.

I suggested various ways in which pictures from magazines, newspapers, travel folders, etc., may be

used to illustrate features studied in earth science. Such pictures may be placed on a bulletin board with explanations or questions, or projected on a screen by means of an opaque projector. The children may be encouraged to find pictures for themselves illustrating various topics.

Each student in the course was required to make some sort of a teaching aid which might be used for earth science instruction in the grades. They produced models of volcanoes, valleys in various stages of development, glaciated terrain, sand dunes, and shoreline features. They also constructed charts to show time belts, ocean currents, and various characteristics of rocks and minerals.

In order to promote additional interest in earth science among the students generally I organized an Earth Science Club. The club conducts field trips and excursions to local museums. The members are preparing a radio program for presentation over a local station. Another undertaking on which they are working is a handbook of "Free and Inexpensive Earth Science Teaching Aids." This will list sources from which grade school and high school teachers may secure booklets, maps, models, films, slides, etc. It will also give suggestions on activities and demonstrations.

Student reaction to these efforts has so far been gratifying. They say they have to work harder in my "Global Geography" than in any other course but that they do not mind because they get more out of it.